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1.	Your reference	571GB
2.	Patent application number *(The Patent Office will fill in this part)*	0220158.0
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Renishaw plc New Mills Wotton-under-Edge Gloucestershire GL12 8JR
	Patents ADP number *(if you know it)*	2691002
	If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4.	Title of the invention	Method Of Scanning
5.	Name of your agent *(if you have one)*	M J Fowler et al
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Renishaw plc, Patent Department New Mills Wotton-under-Edge Gloucestershire GL12 8JR
	Patents ADP number *(if you know it)*	0002691003

		Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	–	–	–

		Number of earlier application	Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	–	–

8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	Yes

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Description	11
Claim(s)	0
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Priority documents	0
Translations of priority documents	0
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	0
Request for preliminary examination and search *(Patents Form 9/77)*	0
Request for substantive examination *(Patents Form 10/77)*	0
Any other documents *(please specify)*	0

11. I/We request the grant of a patent on the basis of this application.

Signature Date 30.08.02

AGENT FOR THE APPLICANT

12. Name and daytime telephone number of person to contact in the United Kingdom A Iles 01453 524524

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METHOD OF SCANNING

This invention relates to a method of scanning an object and in particular a method of determining when or where a scan is complete.

One conventional method used to designate the end of a scan is by inputting coordinates to the scanning device which define one or more end points. The coordinates are chosen so that the whole of the object to be scanned lies within the one or more end points. A problem with this method is that it requires extraneous scanning to be carried out.

An alternative method, which may be used with circular or helical scans, is to begin the scan at the furthermost position from a predetermined origin or centre point of a scan. In this case the end of the scan is when the scanning device reaches this origin or centre point. A problem with this method is that it can require complicated set-up which is time consuming.

According to a first aspect of the present invention there is provided a method of determining an end point of a procedure for scanning an object comprising the steps of;

a) defining an origin of a scanning process;

b) scanning an object with scanning means wherein the object and scanning means are movable relative to each other;

c) selecting data points on at least one scan line in at least one orientational direction from the origin;

d) storing the selected data points;

e) analysing the selected data points;

f) comparing the analysed data to criterion which define the end point of a scan for that object; and

g) stopping the scan when the criterion have been met by the analysed data.

The method according to the invention allows automatic determination of the end point of a scan and thus enables unmanned operation and potentially automatic switch-off of motor drives for the scanning process.

Steps c-f may be performed within the scanning means or in a separate processor which may control the scanning process. The storage of the selected data points is preferably temporary.

Preferably data is selected for a plurality of orientational directions from the origin.

The invention will now be described by way of example and with reference to the accompanying drawings, of which:

Fig 1 shows a scanning device which is suitable for use with the method of the invention;

Fig 2 shows an alternative device which is suitable for use with the method of the invention;

Fig 3 is a flow diagram showing different steps according to the invention;

Fig 4 shows diagrammatically how the data from a scan is selected; and

Fig 5 shows a secondary benefit of the invention.

Fig 1 shows a coordinate measuring machine 1 having a

base 2 and a gantry 3 which is movable with respect to the base along a y-axis. A quill 4 is mounted on and movable with respect to the gantry along an x-axis. The quill 4 has a probe 5 mounted thereon, the probe 5 having a stylus 6 with a tip 7 which can be used to scan the surface of an object 8 located on the base 2. The probe 5 is movable along a z-axis. In this example the x,y and z axes are perpendicular to each other.

During a scanning process, the probe 5 moves relative to the object 8 in a predetermined manner, such as by scanning a pattern having a straight line along the x or y axis, radially about the sample or along a helical path.

The stylus 6 of device 1 has some limitations when it comes to detecting undercuts for example, if object 8 were inverted. For this reason, different styli may be used such as disc or star shaped. A star shaped stylus has four tips lying in the x,y plane i.e. at 90° to stylus tip 7 enabling undercuts to be probed accurately.

Fig 2 shows a scanning device 21 having a base 22 and a back portion 23 which has an LVDT probe 24 attached thereto. The probe has a scanning tip 25 which is movable along an axis designated by the letter a in this case axis a is at 45° to a vertical axis z. Mounted on the base 22 is a sample holder 26 onto which an object 27 may be placed for scanning. The probe 24 and the sample holder 26 are relatively movable along vertical axis z and the sample holder 26 is rotatable about axis z.

During a scanning process, the sample holder 26 rotates about the z-axis whilst the probe 24 and the sample holder 6 are moved relative to one another along the z axis.

Fig 3 shows a flow diagram which details the different steps of the invention. This will now be discussed in relation to two different embodiments of the invention.

In a straight line scanning pattern for example, in Fig 1 when the probe 5 is moved along the x axis only (movement along the y axis or a diagonal in the x,y plane are other examples) or in Fig 2 when there is only vertical or horizontal (rotational) movement, data from only one scan line may be scanned.

An origin of the scanning process 100 is defined. This may be at any co-ordinate within the working envelope of the machine, but is preferably close to the object to be measured in the x,y plane and at a suitable position along the z axis for example, at the base 2 of the machine 1 in Fig 1, so that all the relevant data is captured in as short a time as possible.

The scan is initiated 200 and the probe and object are relatively moved along the scan line. Data is selected 300 from the scan and stored 400. The selected data is then analysed 500 and compared with criterion 600 which determines when the scan ends 700. Until the criterion is met, the scan and data collection continues 800.

In the case shown in Fig 1 with the probe 5 at the (x,y) coordinate shown, the criterion could be, if the scan begins at the base 2, that the x co-ordinate

increases to a maxima, then decreases. Once this occurs, the scan is ended 700.

Alternatively, the complete profile of the object could be scanned and the criterion could be an increase followed by a substantially constant value, then a decrease followed by a constant value in the z direction.

This procedure could be repeated, scanning a plurality of individual scan lines eventually resulting in a complete scan of the object or, alternatively, the data from one or more scan line(s) could be used to define the start (origin) and end point(s) of a different scanning procedure for example, a radial or helical scan.

In a radial or helical scan i.e. when the scan is not in a straight line, the procedure is as follows, firstly an origin of the scanning process must be defined 100. For scanning device 21 (Fig 2) this is preferably defined as lying on the centre of rotation of the sample holder 26. This requires an object 27 to be aligned on the centre of rotation with a reasonable degree of accuracy. This is preferred for a number of reasons including the fact that the probe has a zone in which it will be most accurate which tends to be away from the limits of its motion; the processing means which converts data points from a scan into a three-dimensional model often uses the rotational axis a as a reference so analysis of selected data is simplified; and the stability of an object on the sample holder is increased. A certain amount of misalignment, for example if an object is centred by eye, will not affect

the accuracy of results indeed, an object may be placed near the circumference or edge of the sample holder however this is less desirable.

For the purposes of determining the end of scan the absolute position along the rotational axis is not important, however the relationship of different pieces of data on this axis is important as will be described later.

For scanning device 1 (Fig 1) the origin may be at any coordinate within the working envelope of the machine. It is preferable that the origin is away from the ends of the scales along which the device 1 moves on each axis. The position of the origin may also be influenced by the pattern of the scan to be performed.

Secondly, the scan 200 of an object 8,27 begins. Various data points which are captured during the scan are selected 300 based on predetermined requirements and copied to a separate storage area 400 from that of the complete scan data. If the origin is considered as the centre of the circle lying in a plane perpendicular to the z-axis then, for example, one data point for every 10° of rotation around that circle may be selected however, this may be increased to every degree or two data points per degree if required. All data captured during the scan could, in theory, be selected but this may increase processing time for determining whether the end of the scan has been reached.

As the scan continues, data points which are from the same orientational direction are stored in association with each other such that their relative positions

along the z axis are maintained. For example, this could be as a table with the orientational direction along one side and the order of data capture along the other producing sets of data. In this manner, a plurality of splines of data are created.

The data points once stored are analysed 500 and compared with previous data within the set to determine if the criterion has been met 600. This occurs during the scanning process to enable automatic determination of the end of the scan without post-processing of the data. As the data points within a set all lie on an orientational direction the (x,y) coordinates of the data points can be converted into a distance from the origin on that direction. Changes in this distance reading or even when the distance becomes constant are used to set the criterion for whether the end of a scan has been reached. Referring to Fig 2, if the scan begins at the bottom of the object 27 i.e. at the surface of the sample holder 26, the criterion for the end of scan would be when the distance remained constant for two data points within each set, i.e. when the probe tip 5 had reached point 28. The fact that the distance had decreased and subsequently increased earlier on in the scan is not important in determining the end of the scan.

If the scan began at the top of the object 27 a suitable criterion would be when the data sets increased on two subsequent rotations following a minimum distance from the origin being attained.

The criterion for determining the end of a scan may be set as any number of completed circles which lie in a

plane perpendicular to the z-axis achieving either the desired change or consistency of distance from the origin. Certainly at least two is recommended in order that the surface deviations do not cause premature cessation of a scan. Also, due to non-symmetry of some objects, it is preferred that criteria are set which includes that compliance of a certain number of the data sets with the distance criterion is required. For example when 95% of the sets of data meet the distance criterion as otherwise a scan could continue indefinitely and require manual termination.

Once the criterion or criteria have been met, the scan is automatically ended 700. The termination of the scan could also be used to trigger switching off the motors within the scanning device that control the relative motions during the scan. Of course, for the device 21 of Fig 2, the scan could be controlled by a single motor in which case the sample holder would describe a helical path during the scanning process.

As an alternative to determining the change or consistency in distance of the data within data sets from the origin or when a change in direction of this distance has occurred, the information could be used to determine the change in gradient of the slope of each spline. A person skilled in the art would appreciate that there are other techniques that can be used.

Fig 4 shows a tooth 30 which will undergo a scanning process according to the invention. As the tooth 30 is scanned (not shown) data points from certain predetermined orientational directions from the defined origin of the scan are selected from all the data

captured during the scan. These splines of data can be visualised as being lines of longitude 31 on the surface of a globe which has the defined origin at its centre.

Analysis of the data produces a distance measurement from the origin which is compared to previous measurements in that data set and the criteria of an end of scan to determine whether such an end has been reached.

Fig 5 shows a secondary benefit of the invention. For certain objects which have irregular shapes, it can be difficult to mount the object on a sample holder in such a way that all parts of the surface of the object are accessible during scanning. This is illustrated by a tooth 40 which has a re-entrant point 41 which does not allow the probe tip 42 to accurately scan this part of the tooth 40 as the tip 42 is prevented from touching the surface by an overhang at the re-entrant point 41.

During a conventional scanning process, this re-entrant point 41 could be missed as data readings would be collected at the point of re-entry as the probe tip 42 would remain in contact with the tooth 40. If a re-entry point were missed then the scan would be incomplete and, depending on where the re-entry point were on the tooth profile, a coping manufactured to replace that outer tooth shell may not fit on the matching tooth stump properly. However, by taking selected data points and converting them to distances from the origin along splines (see Fig 3 reference number 31) re-entrant points which are of significant

size (greater than the size of the probe tip) can be identified at the time of scan enabling realignment of the object or tooth immediately. This is because the re-entrant region would show up as a reduction in the distance from the origin and is likely to occur for a number of selected data points and for a number of rotations of the sample holder. Thus, there would be an inconsistency when compared with other data proximate to that region. It is unlikely that such a re-entrancy would stop a scan as less than the proportion of data sets than required would meet the criteria but it could be indicated to an operator to show a problem. One way this could be achieved is by visualising the splines of data on a monitor, the colour could change when a change in direction of the distance is detected.

If such a re-entrant point is detected then the scan may be stopped for realignment of the object or tooth or if it is not discovered until the end of the scan the operator could, by quickly checking the results, establish that a point of re-entry did occur and redo the scan. This would reduce the expense in producing replacement teeth or parts of teeth as inaccurate crown shells would not be manufactured only to find they are inaccurate.

Referring now to Fig 4, the end of a scan which starts at the top or chewing surface of the tooth would be defined by the criteria that 90 or 95% of the sets of data would go through a maxima of distance from the origin followed by movement towards a minima, i.e. the distances of data points gradually increases then decreases for two or three revolutions of the sample

holder, this point is called the margin or preparation line 32 and defines a tooth position with respect to the gum line so it is an important part of the scan.

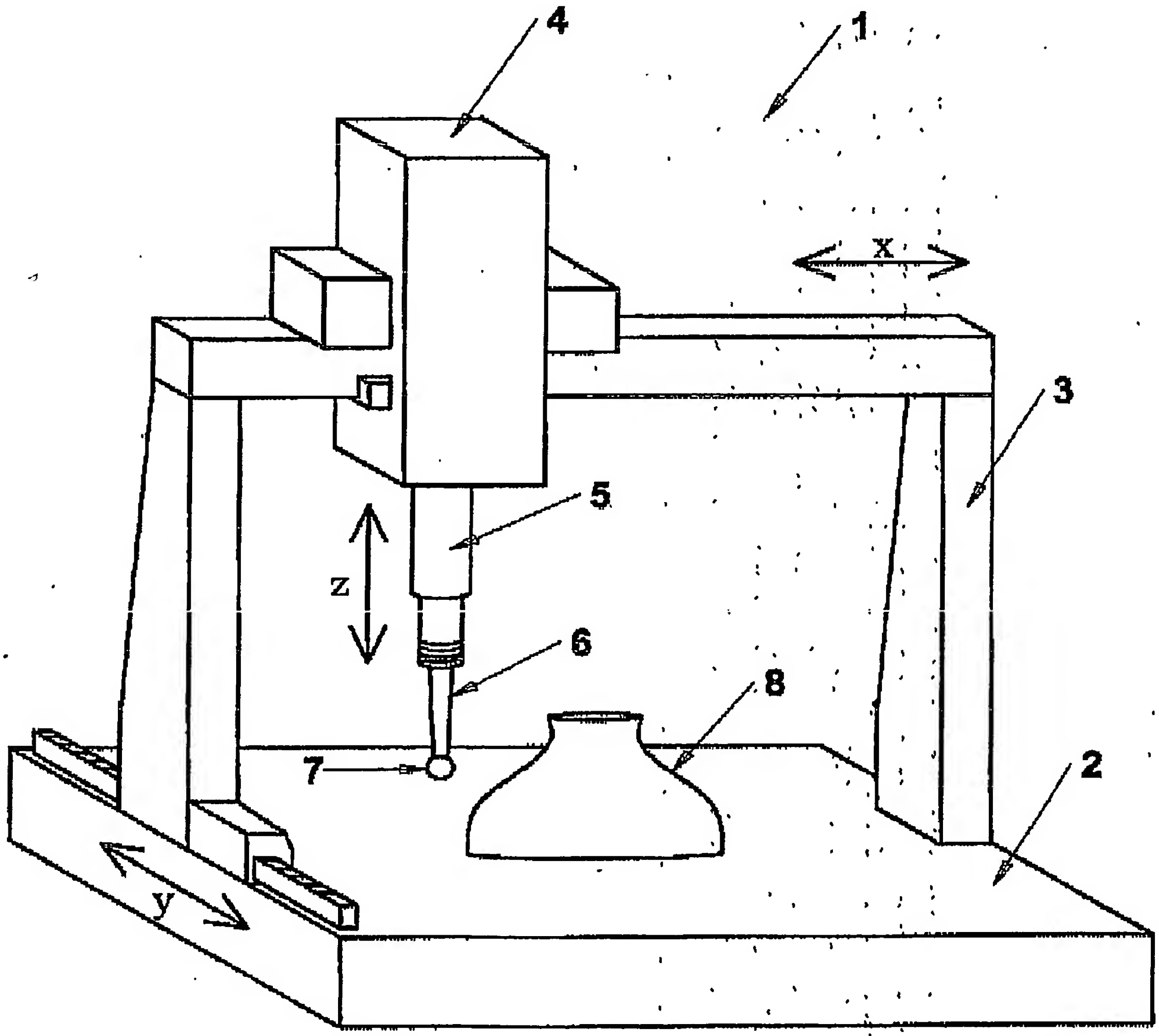

Figure 1

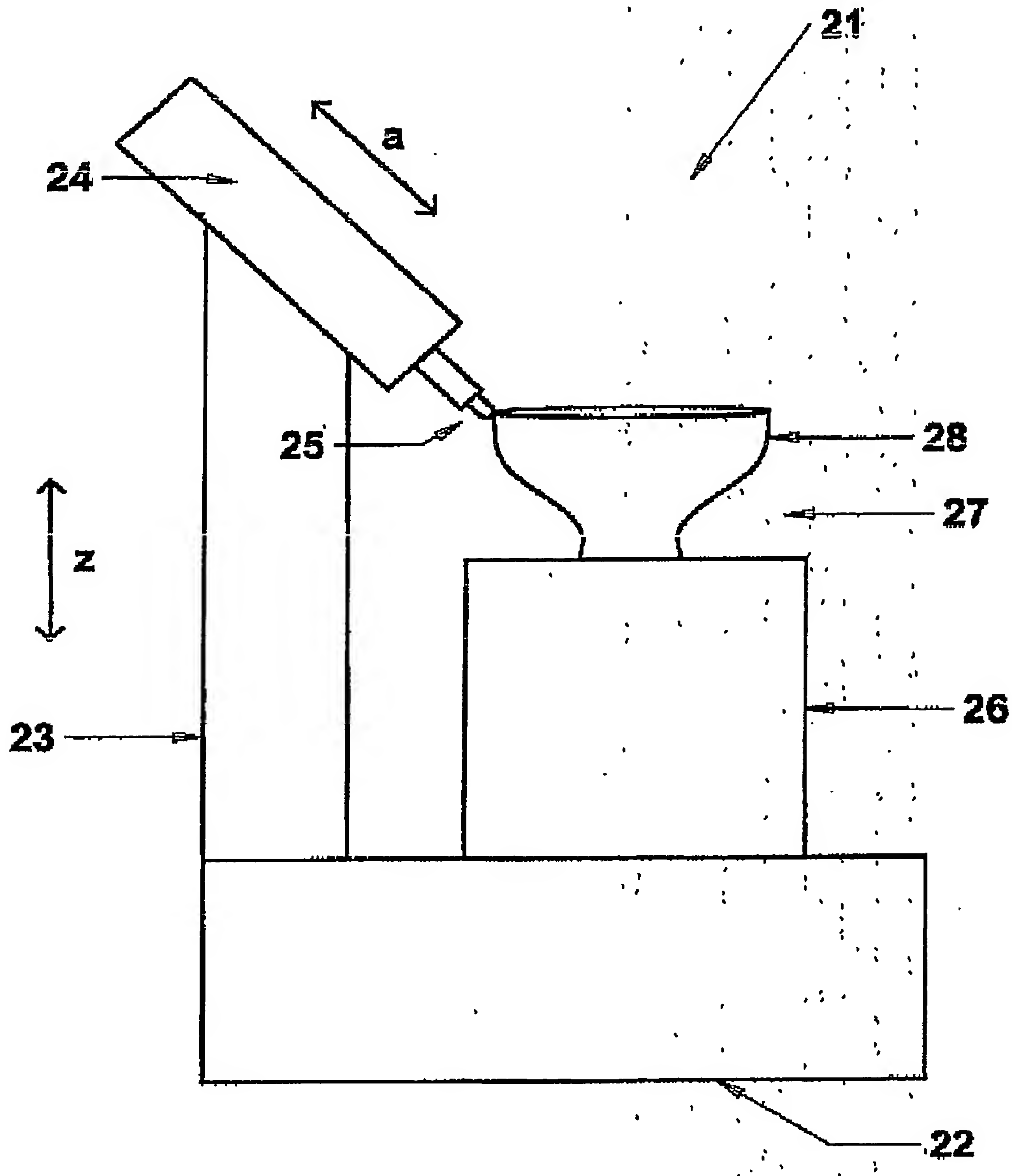

Figure 2

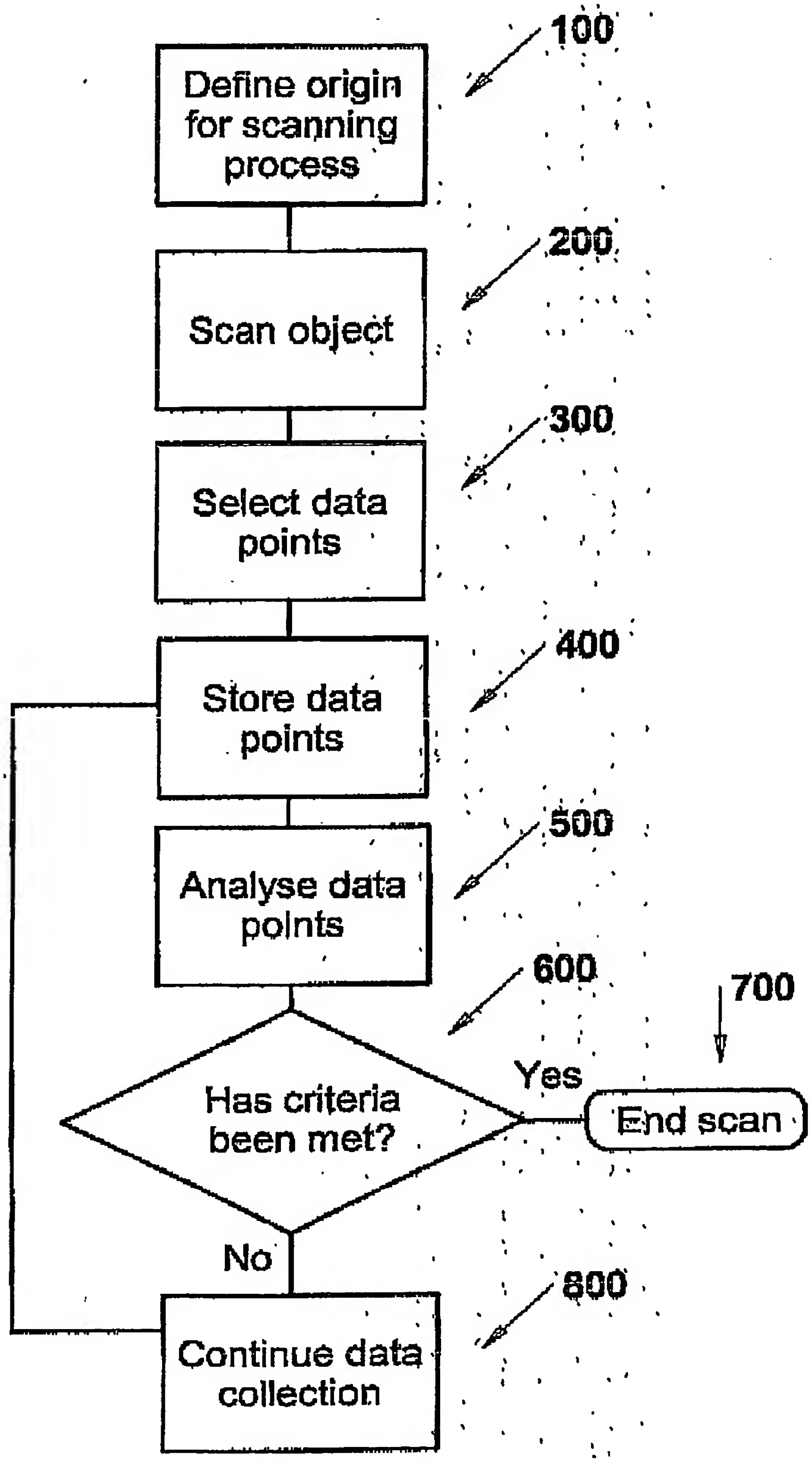
100
Define origin for scanning process
200
Scan object
300
Select data points
400
Store data points
500
Analyse data points
600
Has criteria been met?
Yes
700
End scan
No
800
Continue data collection

Figure 3

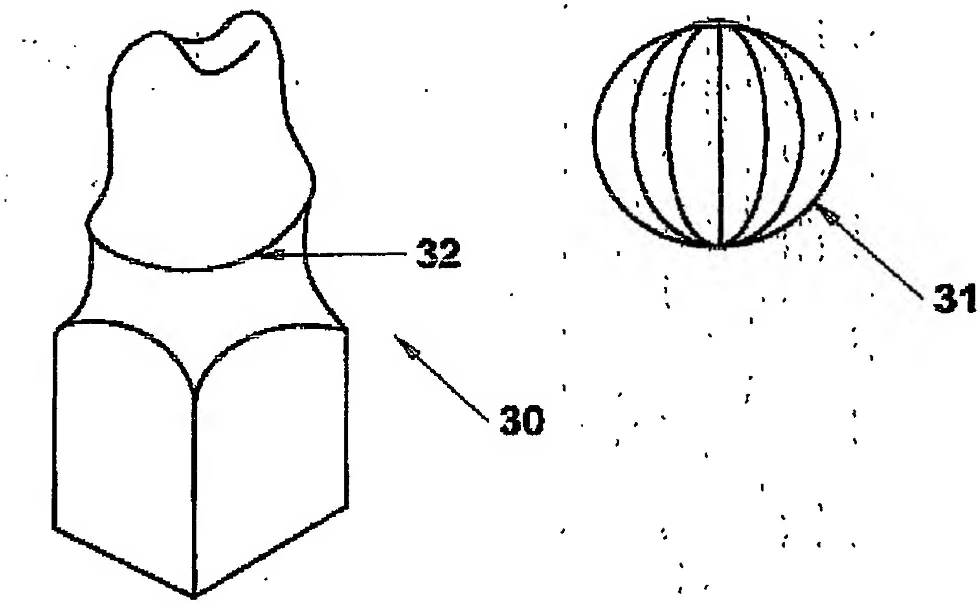

Figure 4

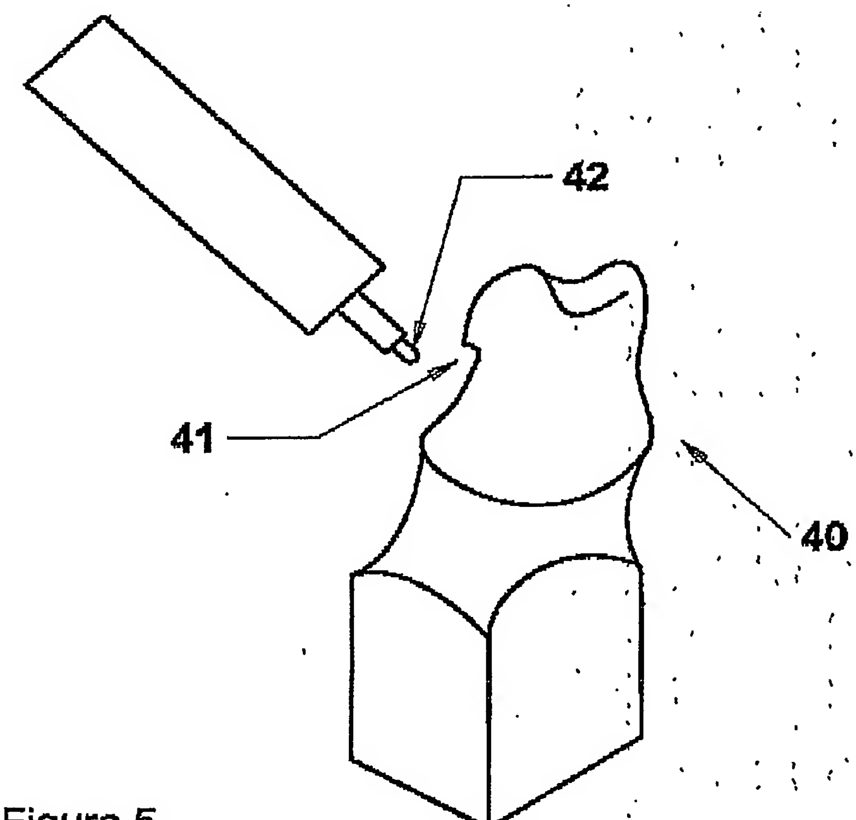

Figure 5